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### **REMARKS**

Claims 1-29 are pending in the application. Claims 1-29 are rejected. The Examiner is respectfully requested to reconsider and withdraw the rejections in view of the amendments and remarks contained herein.

### **REJECTION UNDER 35 U.S.C. § 103**

Claims 1-29 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Vyders (U.S. Pat. No. 6,389,364) in view of Kemp (U.S. Patent No. 6,419,478) and further in view of Suetake (U.S. Pat. No. 6,032,525). This rejection is respectfully traversed.

The Office Action states that locating two thermistors on either side of the valve of Vyders is considered an obvious matter of engineering design choice. It is asserted that flow sensor operation is not changed as long as both thermistors are in the fluid flow path. Applicants respectfully traverse the foregoing assertions. Applicants respectfully submit that replacing the flow sensor described in Vyders with thermistors would drastically change the operation of the flow sensor.

Vyders discloses a mass flow controller that uses a capillary-type flow sensor 26 to measure and regulate gas flow. Two resistive wound coils 28 and 30 are wrapped around a capillary tube 32 (FIG. 3; col. 3, lines 45-50). In a mass flow controller having a capillary-type sensor, gas is divided into two flow paths. A known fraction of actual flow is forced into the capillary tube. Heat transfer between the resistance coils results from interactions with the molecules of the flowing gas, independent of temperature

fluctuations. Because the mass flow controller measures and regulates molecular flow, it provides the most reliable, repeatable, and accurate method for delivering material at a desired rate from a supply volume to a process. Dieball, Mass Flow Controllers Enter the Mainstream, Sensors Online, [www.sensorsmag.com/articles/0800/14/main.shtml](http://www.sensorsmag.com/articles/0800/14/main.shtml). One advantage of the mass flow controller of Vyers is a more accurate approximation of the sensor flow rate signal to enable a more precise and responsive control of the gas flow in a process (col. 2, lines 56-61).

The coils 28 and 30 of the Vyers sensor surround a flow path formed by the capillary tube 32, a different flow path from the actual flow 24 into the valve 58. If the flow sensor 26 were replaced by thermistors on either side of the valve 58, the thermistors would be in the actual flow 24, would be incapable of sensing a molecular flow rate, and clearly could not provide the same measurement precision as the capillary device 26. The controller of Vyers would lose considerable accuracy and be rendered unsatisfactory for its intended purpose. MPEP 2143.01. Applicants therefore submit that two thermistors would not be an obvious replacement for the Vyers capillary-type sensor.

#### CLAIMS 1 and 10

With reference to independent claims 1 and 10, the claims include “a first temperature sensor that senses temperature of gas entering the valve” and “a second temperature sensor that senses temperature of gas leaving the valve”. None of the references cited in the Office Action, alone or in combination, teach or suggest the foregoing recitations. To establish *prima facie* obviousness, all claim limitations must be taught or suggested by the prior art. MPEP 2143.03.

It is asserted in the Office Action that it would have been obvious to modify the system of Vyers to include the use of a pair of thermistors for measuring gas flow in view of Suetake. Suetake discloses a thermistor Rh used for flow detection in a fluid passage 19 (FIG. 4 and 5; col. 2, lines 7-8). The thermistor Rh and a fixed resistor Rm are used to detect flow. Although Suetake teaches a second thermistor Rk, the thermistor Rk apparently is exposed, not to the passage flow path, but to atmosphere (FIG. 1 and 4; col. 6, lines 48-50; col. 10, lines 56-60). Furthermore, Suetake does not teach or suggest a valve. The thermistor Rk does not sense “temperature of gas entering the valve” or “temperature of gas leaving the valve”, as recited in claims 1 and 10.

For at least the foregoing reasons, Applicants submit that independent claims 1 and 10 are not obvious over Vyers in view of Kemp and Suetake. Applicants further submit that when claims 2-9 (dependent on claim 1) and claims 11-18 (dependent on claim 10) are considered together with the recitations of claims 1 and 10, claims 2-9 and 11-18 also should be allowed.

#### CLAIM 19

Referring to independent claim 19, the claim recites “...a first temperature sensor in an inlet of the valve and a second temperature sensor in an outlet of the valve, ...from which is obtained a gas flow rate through an inlet chamber and an outlet chamber of the valve;...” None of the references cited in the Office Action, alone or in combination, teach or suggest the foregoing recitations. As discussed above, it would not have been obvious to replace the flow sensor of Vyers with thermistors on either side of the valve of Vyers. To establish *prima facie* obviousness, all claim limitations

must be taught or suggested by the prior art. MPEP 2143.03. For at least the foregoing reasons, Applicants submit that independent claim 19 is not obvious over Vyers in view of Kemp and Suetake. Applicants further submit that when claims 20-21 (dependent on claim 19) are considered together with the recitations of claim 19, claims 20-21 also should be allowed.

#### CLAIM 22

Independent claim 22 recites “determining temperatures of the inlet and outlet” of a gas valve and “determining a flow rate adjustment based on the temperatures”. None of the references cited in the Office Action, alone or in combination, teach or suggest the foregoing recitations. As discussed above, it would not have been obvious to replace the flow sensor of Vyers with thermistors. To establish *prima facie* obviousness, all claim limitations must be taught or suggested by the prior art. MPEP 2143.03. For at least the foregoing reasons, Applicants submit that independent claim 22 is not obvious over Vyers in view of Kemp and Suetake. Applicants further submit that when claims 23-25 (dependent on claim 22) are considered together with the recitations of claim 22, claims 23-25 also should be allowed.

#### CLAIM 26

Referring to independent claim 26, the claim recites an improved gas appliance, the improvement comprising “a pair of thermistors configured to indicate a gas flow rate through the valve; and a stepper motor that drives the actuator in response to the indicated gas flow rate.” None of the references cited in the Office Action, alone or in combination, teach or suggest the foregoing recitations. As discussed above, it would not have been obvious to replace the flow sensor of Vyers with thermistors. To establish

*prima facie* obviousness, all claim limitations must be taught or suggested by the prior art. MPEP 2143.03. For at least the foregoing reasons, Applicants submit that independent claim 26 is not obvious over Vyders in view of Kemp and Suetake. Applicants further submit that when claims 27-28 (dependent on claim 26) are considered together with the recitations of claim 26, claims 27-28 also should be allowed.

#### CLAIM 29

Referring to independent claim 29, the claim recites a gas valve having “an inlet temperature sensor, an outlet temperature sensor, and a control for controlling the stepper motor to operate the valve member in response to the temperatures sensed by the inlet temperature sensor and outlet temperature sensor.” None of the references cited in the Office Action, alone or in combination, teach or suggest the foregoing recitations. As discussed above, Vyders does not disclose a gas valve inlet temperature sensor and outlet temperature sensor, nor would it have been obvious to replace the flow sensor of Vyders with temperature sensors in the actual flow path 24. To establish *prima facie* obviousness, all claim limitations must be taught or suggested by the prior art. MPEP 2143.03. For at least the foregoing reasons, Applicants submit that independent claim 29 is not obvious over Vyders in view of Kemp and Suetake.

Accordingly, the prior art alone or in combination fails to teach or suggest all of the limitations of claims 1-29. Therefore, reconsideration and withdrawal of the present rejection of claims 1-29 is respectfully requested.

## CONCLUSION

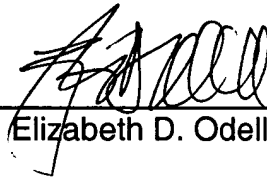
It is believed that all of the stated grounds of rejection have been properly traversed, accommodated, or rendered moot. Applicant therefore respectfully requests that the Examiner reconsider and withdraw all presently outstanding rejections. It is believed that a full and complete response has been made to the outstanding Office Action, and as such, the present application is in condition for allowance. Thus, prompt and favorable consideration of this amendment is respectfully requested. If the Examiner believes that personal communication will expedite prosecution of this application, the Examiner is invited to telephone the undersigned at (314) 726-7521.

Respectfully submitted,

Dated:

July 23, 2004

By:

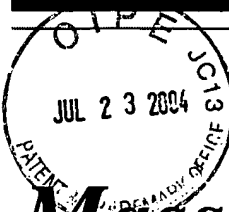


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◀TOC

# *Mass Flow Controllers*

## Enter the Mainstream

Originally developed to control gas vapor deposition in semiconductor fabrication, mass flowmeters and controller can now be found in almost every industry that requires precise measurement or control of low-flow clean gases.

Andy Dieball,  
Sierra Instruments, Inc.

In most processes the critical variable is mass, not volume. Volumetric flow measurements are less reliable than mass flow measurements because changes in gas temperature and pressure change the density of a fixed volume of gas. In the control system, additional errors can be propagated by backpressure fluctuations in the process being monitored.

In contrast to rotameters, turbine meters, and other volumetric flow devices, thermal mass flow meters (MFMs) and mass flow controllers (MFCs) are relatively immune to changes in inlet temperature and pressure. The MFM/MFC is the only device capable of providing direct measurement of mass flow (see Table 1). Most other methods measure volumetric flow (Q) and require separate measurements of pressure (P) and temperature (T) to calculate density and mass flow (m). Because the MFC measures and regulates molecular flow, it provides the most reliable, repeatable, and accurate method for delivering material at a desired rate from a supply volume to a process.

### Table 1

#### Comparison of Volumetric vs. Mass Flow Measurement

Flow Meter Type	What Does It Measure Directly?	Comments
Turbine meter	Q	Need P, T
Positive		



displacement	$Q$	Need P, T
Orifice plate	$Q^2$	Need P, T✓
Rotameter	$Q^k$	Need $P^m$ , $T^n$
Thermal	• $m$	Measures mass directly

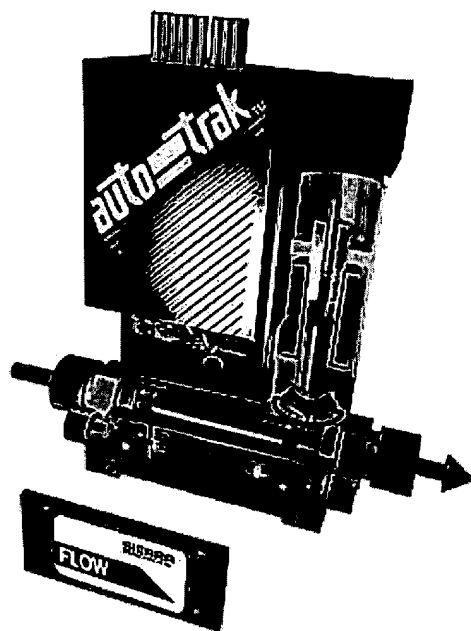
Accurate, repeatable gas flow control improves combustion and chemical reactions, facilitates analysis, and reduces material waste. Originally developed for chemical vapor deposition in the semiconductor industry, capillary-type thermal MFCs are now widely used in laboratory, continuous process, discrete manufacturing, and QA applications.

### The Thermal Sensing Principle

Gas enters the flow body and divides into two flow paths (see Photo 1). Most of the flow goes through the laminar-flow bypass, creating a pressure drop that forces a known fraction of the flow through the sensor tube.

Two resistance temperature detector coils around the sensor tube direct a constant amount of heat into the gas stream. Heat transfer between these elements results from interaction with the molecules of the flowing gas, independent of pressure or temperature fluctuations.

In actual operation, the gas mass flow carries heat from the upstream coil to the downstream coil. The downstream coil therefore has a higher temperature and more resistance than the upstream coil. The coils are legs of a bridge circuit with an output voltage proportional to the difference between the coils' resistance, which in turn is proportional to the mass flow rate in the capillary tube. The two other parameters, heat input and coefficient of specific heat, are constant (see Figure 1).



**Photo 1.** The mass flow controller integrates a thermal mass flow sensor with a servo control valve and PID electronics.

### The Control Valve

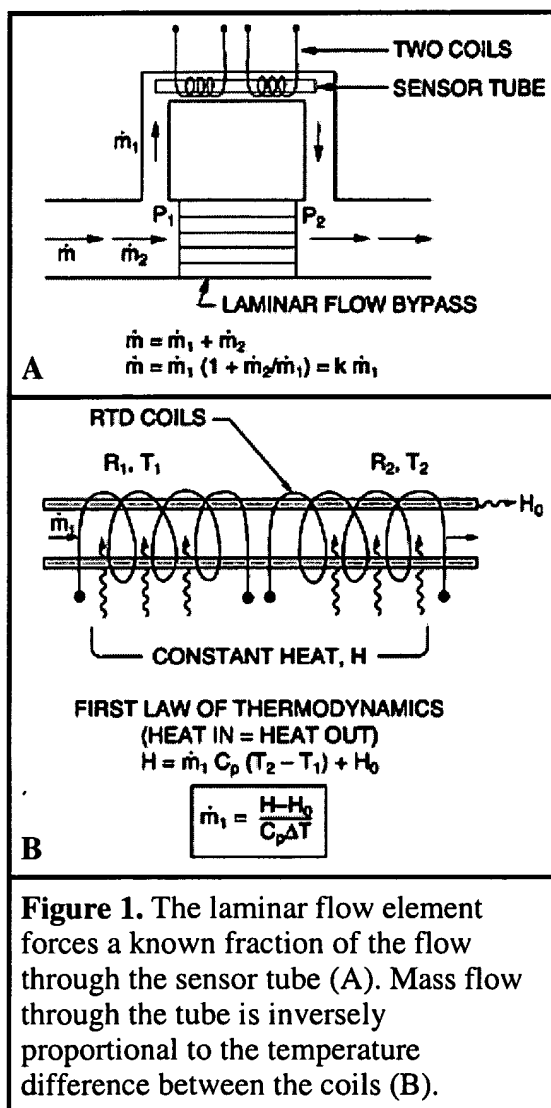
In the MFC, the gas leaves the sensor and the bypass and flows through the servo control valve. Most MFCs incorporate an electromagnetic valve, similar to an on/off solenoid valve, except that the current to the valve coil is modulated so that the valve plug assumes the exact height above the valve orifice necessary to maintain the commanded flow. Built-in PID electronics allows the device to maintain continuous proportional control by comparing the measured sensor signal to the commanded flow rate. MFC control valves are available in a variety of materials, in either normally open or normally closed configurations, and with a wide range of input, output, and command signals.

### Instrument Accuracy

The accuracy of MFMs and MFCs is determined by two factors: flow calibration and repeatability. Proper instrument calibration ensures starting point accuracy, and repeatability is the measure of continuous performance-to-specification over the lifetime of the device. Most thermal MFMs and MFCs are specified at  $\pm 1\%$  of full-scale accuracy and  $\pm 0.25\%$  of full-scale repeatability.

Thermal MFMs and MFCs are gas-specific devices and must be calibrated with either the actual gas or a reference gas. This "inconvenience" has led to the development of many "fixes" in the industry, and is driving the development of smarter devices. For the time being, however, primary calibration with the actual gas or a gas of similar molecular characteristics is the only way to achieve accurate starting point accuracy.

Several factors can affect repeatability. High-stability materials and electronic components, and precise internal voltage and current



regulation prevent long-term drift. Sensor and bypass design also plays a major role in preventing errors caused by contamination and clogging. "U"-type sensor tubes exhibit residual stresses from bending, which can cause long-term strains and unraveling of the sensor coils. These sensors are also more likely to develop drift due to contaminant deposits.

Consideration should also be given to the bypass element of an MFM or MFC. Accuracy can be degraded by changes in temperature if the bypass is an orifice, as opposed to a pure laminar flow element (see Photo 2). The orifice or venturi does not provide laminar flow, and the pressure drop is proportional to the square of the bypass flow. In this case, the ratio of bypass flow to sensed flow is not a constant, but instead is a complex nonlinear function with temperature-dependent terms, e.g., gas viscosity. Both the nonlinearity and temperature dependence of the orifice bypass can seriously degrade the accuracy of MFCs.

### Applications for MFMs and MFCs

MFMs and MFCs effectively reduce costs and improve productivity and measurement accuracy in a variety of analytical, process, and OEM instrument applications. Automating gas delivery with an MFC has many advantages. Because the instrument measures and controls mass flow directly, it is unaffected by temperature or pressure changes in the gas stream and can be operated under positive or negative (vacuum) pressures. In laboratory or test applications, it is easier and more efficient to supply a set point to the flow controller than it is to manually adjust a needle valve with a rotameter indication. The MFM or MFC also allows the user to capture important instrument and process information for data analysis, SPC, or quality audits.

Developed originally to control gas vapor deposition in semiconductor fabrication, MFMs and MFCs can now be found in almost every industry. Any operation that requires precise measurement or control of low-flow clean gases can benefit from this measurement technique.

**Gas Moisture Analyzers.** Dry gas is especially crucial to productivity in the semiconductor industry, where there is a clear relationship between gas purity and wafer yield. Moisture levels must be constantly monitored in the parts-per-billion range.

Moisture analyzers, the most commonly used devices to measure moisture concentration, require precisely controlled flows of gas (see Figure 2). Rotameters and needle valves have been used for this



**Photo 2.** A machined stainless steel bypass creates pure laminar flow through the sensor.

purpose but are prone to error because they cannot compensate for pressure and temperature variations in the gas stream.

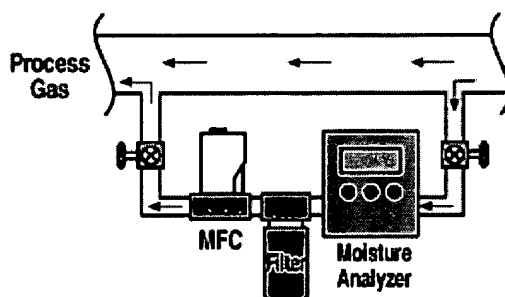
The need for manual adjustments and extensive calculations also contributed to system inaccuracy. The MFC's 1% full-scale accuracy, fast response, and electronic set point control maximizes analyzer reliability and efficiency.

Other analytical applications include sample preparation for gas chromatography and mass spectrometry, flow control to gas generators and gas analyzers, pilot plant development, and gas blending.

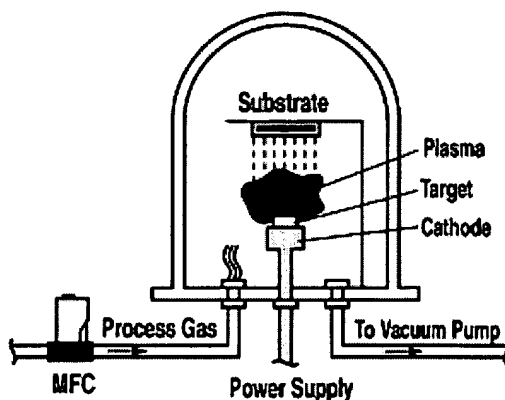
**Vapor Deposition and Sputtering.** In the sputtering process, a negatively charged electrode is slowly disintegrated by molecular bombardment (see Figure 3). The sputtering medium is usually argon because this gas generates sufficient momentum to free atoms from the target. In a vacuum environment, these free target atoms deposit themselves on the surface of the material and form the desired coating or plating.

Maintaining a specified gas flow rate to the vacuum chamber is essential to the process. Typically, vacuum pumping stations require a throttle valve or an orifice-limiting device to control the pump's output when the sputtering gas is introduced. This method is extremely pressure sensitive and can result in inefficient gas delivery and poor product quality. The MFC automatically compensates for changes in system pressure caused by vacuum pump fluctuations, and delivers a precisely controlled gas mass flow rate to the chamber.

Other industrial applications include chemical tank blanketing, sparging airflow to fermenters and bioreactors, combustion control, gas fill, flame control, aluminum purification, laser and plasma welding, and gas blending.

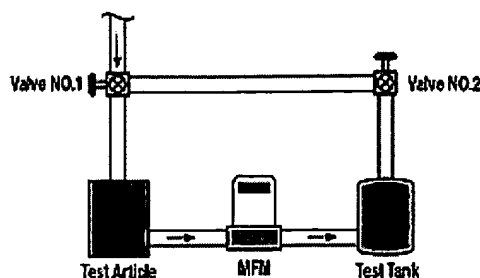


**Figure 2.** Automating gas flow control to the moisture analyzer ensures precise, reliable measurement.



**Figure 3.** In a vacuum process, the mass flow controller automatically compensates for fluctuations in system pressure.

**Leak Testing.** Stringent production test requirements demand fast, accurate, consistent readings that can be electronically stored for analysis. The most precise technique for leak testing is to use a thermal MFM to measure flow rate through a test article (see Figure 4).



**Figure 4.** The mass flow meter's exceptional low-flow sensitivity makes it well suited to leak testing and orifice sizing.

The MFM provides a fast, reliable measurement and produces test data ideally suited to leak detection and diagnostics. Its exceptional low-flow sensitivity allows detection of leaks in both small- and large-volume enclosures. Other test and QC applications include orifice sizing and flowmeter calibration and validation.

### Sizing and Specifying the MFM/MFC

Understanding the principle of operation and calibration requirements of the MFM/MFC helps users specify the best instrument for a particular application. As is the case with most instrumentation, the application conditions must be completely and accurately known to avoid costly mistakes that can delay a startup or even damage the finished product. The most important information requirements for specifying an MFM or MFC are gas type, estimated flow rate, pressure and temperature range, and, for an MFC, the differential pressure.

Once the flow parameters have been defined, the proper flow body size can be determined by following these steps:

1. Consult the manufacturer's product specifications for the acceptable flow range of each flow body.
2. Convert the estimated flow rate to the corresponding units listed in the product specifications.
3. If the gas to be measured is not nitrogen, convert the flow rate to the equivalent nitrogen flow rate. This is done with a linear correlation or a "K" factor, defined as the ratio of the actual gas flow rate to the equivalent nitrogen flow rate. To obtain the equivalent nitrogen flow rate, divide the actual gas flow rate by the K factor.
4. Select the flow body size that will accommodate the estimated flow rate.
5. Ensure that the differential pressure falls within the acceptable range for the selected flow body size and flow rate.

**Table 2****Sizing Example**

<b>Gas:</b>	<b>Argon</b>
<b>Flow rate:</b>	<b>0–3.6 scfh</b>
<b>Inlet pressure:</b>	<b>30 psig</b>
<b>Outlet pressure:</b>	<b>0 psig (atmosphere)</b>
<b>Temperature:</b>	<b>80°F</b>

**Sizing Example.** Consider the application specs in Table 2. Then apply the five steps as follows:

1. Manufacturer: Sierra Instruments Model 840

a. Low-flow body: 0–15 slpm nitrogen

b. Medium-flow body: 0–100 slpm nitrogen

c. High-flow body: 0–500 slpm nitrogen

2. Convert the units:

$$3.6 \text{ scfh} \cdot (1 \text{ H} / 60 \text{ min.}) \cdot (28.316 \text{ l} / \text{ft}^3) = 101.94 \text{ slpm}$$

3. Convert flow rate to equivalent nitrogen flow rate. The K factor for argon = 1.45.  $Q_{\text{EQUIVALENT NITROGEN}} = (Q_{\text{ACTUAL GAS}} / K) = 101.94 \text{ slpm} / 1.45 = 70.3 \text{ slpm}$

4. The application's equivalent nitrogen flow rate of 0–70.3 slpm falls within the capabilities of a medium-flow body.

5. The differential pressure is 30 psid, at 70.3 slpm of nitrogen. This falls within the acceptable range of 5–150 psid.

### Emerging Technology Developments

The innovations and practical improvements emerging or developing in the world of thermal MFMs and MFCs include:

- Improved gas correlations
- Microprocessor-based transmitter design

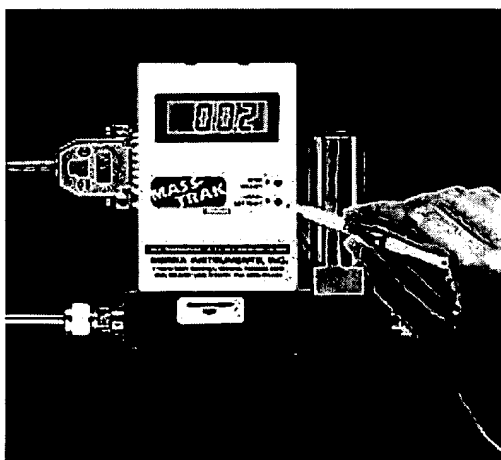
- Product packaging improvements
- Stand-alone configurations

**Improved Gas Correlations.** The established method of calibrating the MFM/ MFC has been to develop K factors that make it easier and more practical to size and calibrate a device. This has been especially important when applying the instrument to toxic or lethal gases because the K factor allows the manufacturer to calibrate the MFC with nitrogen, a safe and inert gas. The disadvantage of this technique is that it does not perfectly model the correlation between nitrogen flow and the actual gas, especially for less-common gases, higher flow rates, and higher pressures. A major breakthrough has been the development of new gas correlation equations that allow the manufacturer to more accurately model the actual gas, resulting in significant improvements in installed performance.

**Microprocessor-Based Transmitter Design.** The development of improved gas correlations, combined with new micro processor-based designs, has greatly enhanced MFC performance and ease of use. Microprocessors allow the manufacturer to calibrate the device with nitrogen and apply it to any gas by merely downloading the appropriate gas equation into the device memory. Better gas equations also improve linearity because of higher resolution of the calibration curve.

Operators also benefit from the flexibility of the new digital MFM/MFC. The ability to load any gas equation into the digital MFC is ideal for multiple gas applications and reduces stocking requirements. Other benefits include self-calibration and diagnostics, digital communication and control, and easier commissioning and field configuration.

**Product Packaging Improvements.** The application base for the thermal MFM/ MFC has grown tremendously in the past 30 years. Initially developed for use in a clean semiconductor wafer fabrication facility, the instrument enclosure did not need to withstand harsh elements or hazardous area conditions. Today, many of these devices are being applied in the pharmaceutical and chemical manufacturing industries and require a much



**Photo 3.** The latest generation of mass flow controllers features onboard display and set point control to facilitate setup and flow rate

more rugged construction. For adjustments.

example, the ultraclean

demands of a pharmaceutical plant expose the MFM/MFC to external cleaning in the form of a chemical washdown that would damage the conventional MFC package. High demand for thermal MFCs in these harsher environments has driven the development of NEMA 4X and explosionproof package designs.

**Stand-Alone Configurations.** The conventional MFC is installed in conjunction with an electronic display and power supply module whose purpose is to provide power, a command signal, and a display of the measured variables. The newest MFCs are available with a local set point and display configuration that is well suited to applications where real estate is scarce, such as in many OEM applications where there is a need to incorporate many components within a secondary product enclosure, or in laboratory applications where benchtop space is limited (see Photo 3).

The conventional MFC also requires a dual-polarity power supply. The stand-alone MFCs are equipped with a single-sided power supply that eliminates the need for expensive and space-consuming power conversion units.

## **MFCs Improve Performance of Pilot-Scale Cell Culture System**

**P**rotein Design Labs (Mountain View, CA) has improved pilot production control by integrating an automated gas-mixing system that incorporates 12 digital MFCs from Sierra Instruments with a B. Braun Biotech Biostat bioreactor. According to associate scientist Paul Sauer, of PDL's cell culture development group, MFCs were specified for two reasons.

First, the group needed to minimize the formation of foam in the bioreactor's headspace. To accomplish this, PDL had to reduce the net volume of air and oxygen gases that were being bubbled into the culture medium. The rotameter PDL had been using was unable to control the low flow rates required. According to the rotameter's flow tube, the flow rate was 60 ml/min., but after Sierra's MFCs were installed the true rate was discovered to be as much as 33% higher. Setting the MFCs at 60 ml/min. significantly reduced the foam.

Second, the MFCs provided more information. By monitoring and metering gas ratios precisely, they proved an elegant and relatively straightforward way of measuring oxygen uptake rate.

The digital MFC also facilitates the cGMP- and FDA-required validation of fermentation processes, which calls for documented evidence of consistency in specifications and quality. This includes



detailed records on specifications, performance, maintenance, and calibration history of all instrumentation devices associated with the bioreactor.

## Summary

The thermal MFM/MFC attributes of excellent low-flow sensitivity, immunity to pressure and temperature changes, and built-in control elements have led to their use in thousands of gas flow applications.

Emerging technological developments and packaging options have made these devices less costly, more reliable, and easier to apply. The benefits of mass flow measurement and automated gas delivery easily outweigh the inconvenience factors associated with the device, and have driven the growing and widespread acceptance of this technology.

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